

Drip irrigation of rice

A water saving technology for enhancing profitability and environmental security

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The use of drip irrigation in irrigated aerobic rice cultivation is a contemporary water-saving strategy. However, inadequate evidence concerning technical feasibility i.e., crop establishment method, planting pattern, drip product and design module, productivity levels, resource conserving capacity and economic viability limited its use in irrigated rice. The results indicate that drip irrigation of aerobic rice not only enhances grain yield but also contributes to water, energy, fertilizer, and labour savings compared to conventional transplanted flood method of irrigation. These incentives are the key to scaling adoption of water-saving technologies in rice, thereby enabling rapid food grain production growth through sustainable intensification to meet the future food demand of growing population under declining resources. The present policies like PMKSY (Pradhan Mantri Krishi Sinchayee Yojana) at National and State level water conservation policy initiatives such as “Telangana State Micro Irrigation Project”, “Andhra Pradesh Microirrigation Project” and “Gujarat Green Revolution Company” are aimed to address higher water productivity in agriculture in water scarce situations. Major challenges to the large-scale adoption of water-saving technologies include farmers’ lack of knowledge about technical and economic feasibility of drip irrigation, traditional habits of cultivating rice and poor linkages among stakeholders. Continued support of research and extension agencies hence the effective scaling up of drip irrigation technology among rice farmers in the country.

Keywords: Drip irrigation, Rice cultivation, Water scarcity

RICE provides the livelihood for about two-thirds of the world population. Conventionally, it is grown by transplanting seedlings into puddled soil (wet tillage) under standing water. This method of rice cultivation utilizes more than 30% of India’s freshwater. Further, the transplanted lowland rice cultivation system is labour-, water-, and energy intensive and become less profitable as the availability of these resources diminished. A major study by the Comprehensive Assessment of Water Management in Agriculture, FAO in 2007, reveals that one in three people today face water shortages – around 1.2 billion live in areas of physical water scarcity, 0.5 billion are

approaching this situation and another 1.6 billion are facing economic water shortage. Similarly, NITI Aayog’s ‘Composite Water Management Index 2019’ pointed out that already 65% area under rice production in India is facing extreme levels of water scarcity. The puddled soil in conventional flooded rice production system also deteriorates the physical properties of soil, adversely affects the performance of succeeding upland crops, and contributes to methane emissions. The prevalent ‘water saving’ technologies such as – saturated soil cultivation, the systems of rice intensification, and alternate wetting and drying irrigation are perceived to

consume more amounts of water than desired.

The aerobic rice system proposed by the International Rice Research Institute is a water-saving production system, where high-yielding rice is grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. In this system, the soils are kept aerobic throughout the growing season. Unlike flooded rice, irrigation—when applied—is not used to flood the soil but to just bring the soil water content in the root zone up to field capacity. Wetland preparation involving land soaking, puddling and nursery raising is abandoned altogether in aerobic rice. Thus, it eliminates water use



Fig. 1. Drip irrigated dry seeded aerobic rice on raised beds

during land preparation and limits unproductive water outflows through seepage, percolation, and evaporation compared to conventional flood irrigation method. However, numerous drying and wetting cycles followed under aerobic rice cultivation system cause mild to moderate water stress affecting crop performance and grain yield. Therefore, drip irrigation as a modern scientific irrigation technology coupled with fertigation in aerobic rice will bring a three-fold transformation in cultivating rice in India with high water-, energy-, and fertilizer use efficiency. It is important to understand the appropriate drip design for rice, its productivity, water use and water productivity under drip irrigation systems. In addition, there is little field level information on whether rice, like other field crops such as maize, sugarcane and cotton can produce higher grain yield and water productivity under drip irrigation compared to flood irrigation. Hence, field trials were conducted at the Water Technology Centre, PJTSAU, Hyderabad to test the technical and economic feasibility of drip irrigation in rice. Additionally, the technology was verified in farmer's fields to get feedback on easiness in adoption, yield levels, economic benefits and acceptance level of technology.

Drip irrigation system in rice field

The precise application of water along with constant wetting techniques would be achievable under drip irrigation. A solid-set stationary hardware drip irrigation system comprising of a pipe network, integral driplines with a very large number of emitters per unit area along the water delivery line at a predetermined spacing distributes water directly to the crop root zone on or below the soil surface tailored to meet crop needs at various growth stages enabling a high degree of water application control (Fig. 1).

The water distribution under dripline is in the form of a wetted strip on the soil surface between crop rows, while most of the irrigated wetted soil volume is below the soil surface. The width of the wetted strip depends mainly on the hydraulic conductivity of the soil whereas the depth is a function of both saturated hydraulic conductivity and gravity. In practice, irrigation scheduling is based on crop evapotranspiration (ET_c), with field water supply matching the daily crop water needs and equivalent to deficit created since previous irrigation event plus application inefficiency losses, if any. Moreover, fertigation opens up new possibilities for using fertilizer programmes based on concentration

of nutrients in the root zone rather than weight basis i.e., kg/ha and can improve yield potential of rice by applying split doses of fertilizers precisely at the right time according to nutrient demand at various crop growth stages and in the right place i.e., vicinity of root zone minimizing losses. Applying nutrients through drip irrigation might create a dense crop rooting pattern composed of numerous small rootlets and root tips, with extensive ramification, and increased root surface area that greatly enlarges the potential for mineral and water absorption (Fig. 2).

Thus, drip irrigation with fertigation strategy can be a better option for rice production which may be adapted to local conditions by altering plant, soil, water and nutrient management practices. Such alterations lead to - (a) induce optimal soil water – air relations, (b) promote root proliferation in water and nutrient rich zone for better-functioning root systems, (c) enhance resource use efficiency by conserving water, energy, fertilizer, agrochemicals and labour, (d) reduce emissions of methane, a potential greenhouse gas (GHG), and (e) enhance farm profitability and environmental sustainability. As the economic value of water increases with growing water scarcity



Fig. 2. Dense root system with numerous small rootlets in drip irrigated rice

worldwide, drip offers an opportunity for farmers to save water. Given the estimate that rice cultivation under flooded conditions uses 30% of the India's fresh water, finding ways to reduce water use to grow rice could have a big impact on access to this resource ensuring food security.

Model drip design components for rice crop

The main control station for a drip irrigation system consists of a pump, a backflow prevention device, a primary filter, a pressure regulator, automatic or mechanical flow control valves, pressure gauges, a water meter, fertilizer injection equipment, and sometimes automation. The pump carries water from the water source (open well, bore well or reservoir) to the system control station. The types of filters used most often in drip irrigation systems are – media (sand or gravel), disc, screen or hydrocyclone filter depending on the quality of irrigation water, and the presence of various substances in it (sand, silt, organic and other foreign material), with respect to the specific requirements of the irrigation system. In this case study, media filter followed by a disc filter downstream were used since the source of water was from an open well with physical and biological substances. Main, sub-main and distribution pipelines carry water through the entire irrigation system, from the pump through the filters, the valves, and onward to the drippers. A single, large water meter at the head of the drip irrigation

system was installed to monitor the flow rate of the entire system. Pressure gauges are located at inlet and outlet of the filter and after water meter to help in the detection of leaks and clogging and in the management of filters, chemical injectors and in

keeping the system in its operating range. Main, sub-main and distribution pipelines carried water through the entire irrigation system, from the pump through filters, the valves, and onward to the drippers. A simple, reliable and low cost ventury fertilizer injector (0.75") was installed as a bypass from the main pipeline to inject water soluble fertilizers. An anti-siphon unit consisting of a check valve and a vacuum breaker is installed in the mainline between pump and fertilizer injector to prevent backflow of fertilizers or other chemicals back into the water source in the event that the irrigation pump stops during the injection. Additionally, surface drip and subsurface drip systems are readily amenable for automation using components such as controllers, solenoid valves, sensors etc.

Bed Configuration and Dripline spacings

The drip irrigated aerobic rice is

usually grown on raised beds. In the present experiment, a beds configuration of 1.2 m centre to centre (Fig. 3) was adopted having a bed width of 0.80 m, furrow width of 0.40 m and height of 0.15 m, with 4 rows spaced 20 cm apart on the bed and one dripline per bed feeding four crop rows placed between two pairs of rows ; (2) Alternatively bed size of 1.5 m centre to centre, width of 1.20 m, furrow width of 0.30 m and height of 0.15 m, with 6 rows spaced 20 cm apart on the bed, and two driplines per bed, each dripline feeding three crop rows. Generally, for field crops including rice drip systems always use flexible polyethylene pipe i.e., dripline of 16-mm diameter with integral drippers. Depending upon local topographical conditions this dripline can be either pressure compensating thick-walled driplines or non-pressure compensating medium or thin-walled driplines. Dripline spacing is primarily influenced by soil texture and the main considerations are uniformity of water application.

Driplines placed on the surface should be "snaked" or left slightly loose and properly aligned between the crop rows to realize a desired uniform wetting pattern. In case of subsurface drip, the dripline installation depth ranging from 5 to 15 cm is adopted depending on the soil type, climatic conditions, rotational crops and farmer's preference. An emitter spacing of 30 to 50 cm would be appropriate in close growing crop like rice depending on soil texture. The

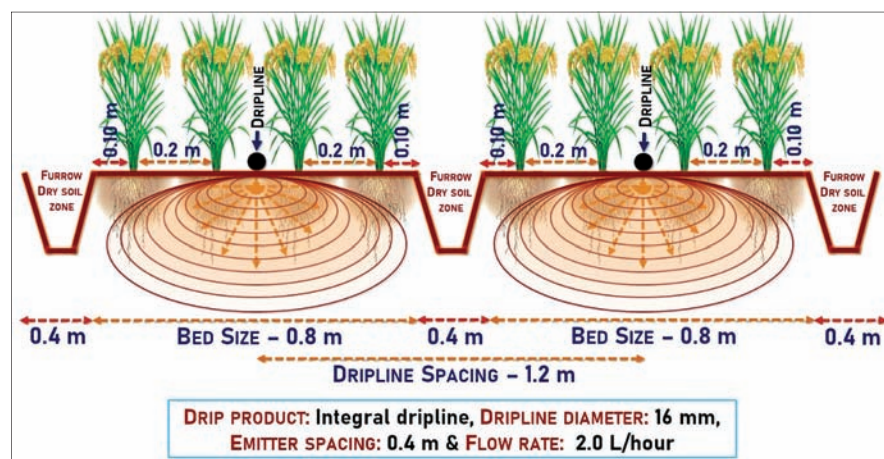


Fig. 3. Bed configuration and dripline layout for drip irrigated rice

emitter spacing may be adjusted to achieve the appropriate application rate. Emitter flow rates ranging from 0.6 to 3.5 L/h were found to be adequate depending upon the soil infiltration rate, application rate desired to satisfy the peak crop water use, water quality, soil salinity and the water availability. Desired wetting patterns can be obtained by selecting the appropriate combination of emitter flow rate and spacing.

Benefits of drip irrigation in rice

Drip irrigation could be one of the most promising options for increasing the efficiency of irrigated rice production in India. Since its introduction in the 1960s, the availability, quality, agronomic management and performance of drip irrigation has been greatly improved. The use of drip irrigation has increased significantly as understanding and benefits in real-time increased with the plastic materials availability, manufacturing processes, emitter designs and availability of suitable water-soluble fertilizers. Drip irrigation in rice is characterized by the following features: water is applied by a low pressure delivery system at a low flow rate, frequently, localized i.e., in the root zone, wetting only partial volume of soil, and system is routinely used to transport fertilizers and other agricultural chemicals through the water to crop.

Today the drip technology figures prominently in proposed solutions to the water crisis. In national and international policy documents, it is seen and promoted as a device to use water more efficiently. The belief in the water-saving potential of drip irrigation is often substantiated with impressive statistics and measurements. Sandra Postal author of *"Pillar of Sand: Can the Irrigation Miracle Last?"* and of *"Last Oasis: Facing Water Scarcity"*, for instance, claims that drip irrigation "... has the potential to at least double crop yield per unit water in many applications, including irrigation of most vegetables, cotton, sugarcane, and orchard and vineyard crops. Further, World Bank Document *"Reengaging in Agricultural Water*

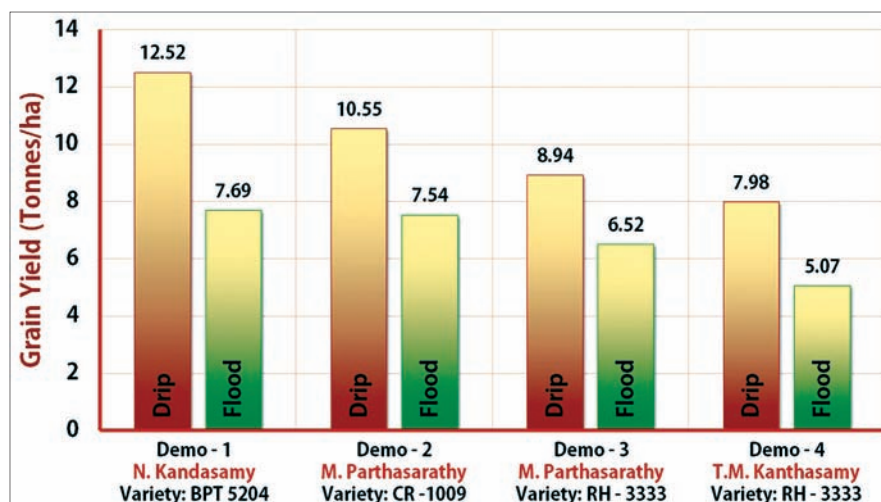


Fig. 4. Rice grain yield: Drip irrigation versus conventional flooding

Management – Challenges and Options” states that, in countries as diverse as India, Israel, Jordan, Spain, and the United States, studies have consistently shown drip irrigation to reduce water use by 30 to 70% and to raise crop yields by 20 to 90%. Efficient water use leads to additional benefits such as the increasing area under irrigation as well as more usage of marginal and degraded lands.

Increased plant growth and yield: Water status of plants drives metabolic process of photosynthesis, which in turn affects the plant growth. Precise delivery of water equivalent to ET_c according to crop developmental stages, continuously maintaining a fairly high soil water potential in the crop root zone eliminating wide fluctuations, coupled with improved nutrient availability via fertigation favoured higher plant water balance and enhanced nutrient uptake in drip irrigated rice. This in turn helped the crop to put forth a greater number of effective tillers, panicles/m², filled grains/panicle and grain weight contributing to higher grain yields. Yields ranging between 7.98 to 12.52 tonnes/ha were registered under drip irrigation in comparison to 5.07 to 7.69 tonnes/ha under conventional flooding method depending on the agroecological conditions, soil type and varieties used (Fig. 4).

Potential savings in water due to increased beneficial use of available water: Drip irrigation of rice on an average reduced water use by 45.25% (43.0 to 48.1%) when

compared to conventional flood irrigation of 3 – 5 cm water depth, owing to partial wetting (irrigation of small portion of soil volume) and elimination of seepage, percolation, free water evaporation losses, and reduced irrigation runoff from the field (Fig. 5).

However, the savings may vary depending on crop duration, soil type, environmental conditions and the attainable on-farm irrigation application efficiency. In practical terms, farmers raising rice crop with drip irrigation require only 779 litres of water to produce a kg of paddy compared to conventional flooded paddy crop (2024 litres). Higher irrigation water application efficiencies in rice will result in reduced withdrawal of groundwater, thus addressing the problem of the declining water table in major rice growing states of India thereby ensuring groundwater stabilization, food and livelihood security. This is an important benefit and a climatic smart adaptation intervention that could help farmers to cope with unforeseen water scarcity situation.

Decreased energy use and Production costs: Drip irrigation of rice has the potential to reduce energy use and electricity bills since the amount of water pumped is considerably lower than conventional flood irrigated crop owing to higher on-farm irrigation application efficiency. Electricity in India is a very precious and costly input and about 1,208.3 electricity units/ha have been saved by using drip (2,363.8 kWh/

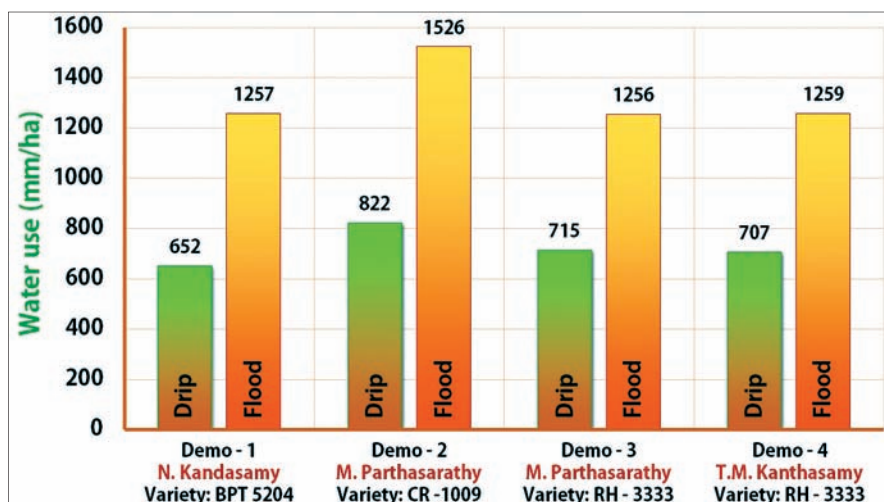


Fig. 5. Rice water use: Drip irrigation versus conventional flooding

ha) compared to flood irrigated rice, 3,572.1 kWh/ha. This represents a net saving of 33.8% in energy use under drip, which in turn reduced electricity bills by ₹ 4834/ha.

Efficient use of fertilizers through fertigation: Drip irrigation offers considerable flexibility in fertilization, a benefit unique to drip system. On an average farmers reported a fertilizer saving of 21–32% in different fields. Improved efficiency in fertilizer use can be attributed to – use of appropriate source of water-soluble fertilizer product (the RIGHT source) based on soil and environmental factors; decreased quantity of applied fertilizer (the RIGHT quantity) because it is applied and distributed where roots are actively concentrated (the RIGHT place) with minimum leaching considering soil test results and targeted yield; improved timing of fertilizer application i.e., frequently, to match nutrient demand by the crop at various developmental phases (the RIGHT time) for better economic return and environmental sustainability.

Improved plant protection: Maintaining dry foliage, which retards the incubation, development and spread of many plant pathogens; less incidence of brown plant hopper and sheath blight incidence was reported by farmers in drip irrigated rice. Additionally, research trials on greenhouse capsicum initiated at PJTSAU show that agrochemicals such as insecticides can be injected through a drip to improve crop

performance.

Dry direct seeding: Drip irrigated rice cultivation method involves sowing seeds into well-prepared dry soil such as drilling and direct seeding using a mechanical seed drill. The water and labour saving generated by dry direct seeding compared with conventional rice-growing practices such as nursery raising, seedling uprooting, land soaking, puddling, transplanting etc, have made this method increasingly popular in irrigated areas where water is becoming scarce. Farmers reported that it could save about ₹ 4,000 to 7,200/ha in cultivation cost. Other main incentives for the adoption of drip-irrigated dry direct seeded aerobic rice by farmers are reduced labour requirements and constant daily wetting of soil maintaining optimal soil water – air relations, which enables improved performance and brings more stability to rice production.

Agronomic benefits: Application of small amounts of water frequently according to crop needs using drip system eliminating flooding, was found to improve soil physical properties and provide opportunities for value chain mechanization, conservation agriculture and diversified crop rotation, making rice a more suitable crop for rotation with upland crops. Improved soil aggregation and oxygenation were also found to enhance root proliferation in the vicinity of wetted strip. Other agronomic benefits outlined by farmers included

improved farm machinery efficiency, along with the flexibility of equipment types (a limiting factor in current rice mechanization), easy and timely harvesting, low incidence of brown plant hopper, absence of aquatic weeds and promptly switching over to a subsequent crop season by reducing the turnaround time for land preparation.

Runoff and ecosystems: Drip irrigation enables higher capacity to capture the incident rainfall in the soil profile during the crop growing season due to higher infiltration of water into an unsaturated soil since there is no standing water in the rice field. This can bring down overland runoff flow and erosion and markedly reduce the agrochemical pollution and nutrient-bound sediment in waterways, which is a common sight in conventional flooded rice ecosystem. Drip irrigation could further reduce runoff in rotational upland crops after rice by facilitating residue incorporation, soil structure improvement, and reduced tillage.

Removal of phytotoxins: Unsaturated soil conditions created through drip irrigation can reduce accumulation of arsenic in rice kernels, a concern for millions of people in developing Asian countries. Likewise, phytotoxins such as phenolic acids, hydrogen sulphide, excess iron and manganese that accumulate from continuous flooding and anoxia are absent.

Other benefits: Drip irrigation of rice may bring in other advantages such as – reducing methane emissions, a potential greenhouse gas; facilitating residue incorporation, thus avoiding straw burning and leading to enhanced nutrient cycling; improved soil microbial and invertebrate activity in the root zone and reduced mosquito and water-borne diseases.

Despite observed successes and possible numerous field benefits, some limitations/problems have been encountered with drip irrigation systems. These include vulnerability to widespread non-availability of specific varieties to suit drip-irrigated aerobic rice farming situations, lack of skill and operational constraints while using drip system among small

Table 1. Economic analysis of drip vs. flood irrigated rice

Symbol	Particulars	Drip	Flood	Gain (%)
		(₹/ha)		
A	Production cost	45,703	58823	22.3
B	Fixed cost of drip spread over 3 crop seasons in year*	39,336		
	a) Life (years)	10		
	b) Depreciation	3,936		
	c) Interest @13%	5,112		
	d) Repairs & Maintenance	1,426		
	Total Cost (b + c + d)	10,431	—	—
C	Total Production + Drip system costs [A + B(e)]	56,134	58,823	4.6
D	Water use (mm/ha)	822	1,526	46.1
E	Grain yield (Tonnes/ha)	10.55	7.54	39.9
F	Selling price – MSP (₹/Tonne)	18,150	18,150	—
G	Gross returns (per ha) (E × F)	191,483	136,851	39.9
H	Net income (per ha) (G – C)	135,349	78,028	73.4
I	Net income (₹/ha) due to drip over Flood irrigation of rice	57,321	—	—
J	Water productivity (kg/m ³)	1.28	0.49	
K	Additional area that can be irrigated (ha) by saved water	0.85	—	—
L	Water required (Litres) to produce 1 kg paddy	779	2,024	61.5

*Average capital fixed cost of dripline spacing – 0.8 m, emitter spacing – 0.4 m with a flow rate of 2.0 litres/hour is ₹ 118,009/ha

and marginal rice growers, high initial system costs, micronutrient (Fe & Zn) deficiencies, increased blast disease, root-knot nematode populations and termite attack.

Profitability

The high cost of the drip irrigation system and assured power supply are the two major hurdles faced by the farmers today for the widespread adoption of drip irrigation in narrowly spaced rice crop. However, the inherent advantage of higher grain yield, input savings *viz.*, water, energy, and fertilizer, and in the presence of minimum support price and functioning markets were found to offset the initial high capital investment on drip system as evident from the economic analysis (Table 1).

Additionally, a substantial amount of saving in cost of production (22.3%) has been noticed with drip when compared to conventional flood method of irrigation in rice especially in labour intensive operations such as: weeding – partial wetting of soil results in limited weed growth; fertigation – injection of water-soluble fertilizers *via* irrigation system (fertigation) minimizes wastage reducing fertilizer rates and costs;

elimination of nursery raising and wetland preparation - land soaking, puddling and transplanting; low seed rate, improved plant protection and reduced water pumping hours etc. The net income with drip irrigation of rice was estimated at ₹ 1,35,349/ha, which was markedly higher (73.4%) than that accrued under conventional flood irrigated rice, ₹ 78,028/ha. The average capital fixed cost required for installing the drip irrigation system (dripline spacing – 0.8 m, emitter spacing – 40 cm with a flow rate of 2.0 litres/hour) for aerobic rice crop works out to ₹ 1,18,009 per ha without any subsidy. However, it is interesting to note that after deducting the state subsidy for drip system provided in different rice growing areas of India, the fixed cost of the drip system for the farmer is very low; it works out to only ₹ 48,270 per ha in Tamil Nadu and ₹ 38,338 per ha in Telangana and Andhra Pradesh. Further, the total benefit of ₹ 1,35,349/ha per season accrued to farmers from the cultivation of rice using the drip system would enable them to repay the whole fixed capital investment on drip at ₹ 1,18,009/ha in the very first year itself (considering 2–3 crops per year) even without accounting for

subsidy. Additionally, water saved (46.1%) by drip in each ha enables the farmer to bring an extra area of 85% under irrigation in water-scarce situations.

SUMMARY

The use of drip irrigation in aerobic rice cultivation is a contemporary water-saving strategy. However, inadequate evidence concerning technical feasibility *i.e.*, crop establishment method, planting pattern, drip product and design module, productivity levels, resource conserving capacity and economic viability limited its use in irrigated rice. The results indicate that drip irrigation of aerobic rice not only enhances grain yield but also contributes to water, energy, and fertilizer savings compared to conventional transplanted flood method of irrigation. These incentives are the key to scaling the adoption of water-saving technologies in rice, thereby enabling rapid food grain production growth through sustainable intensification to meet the future food demand of growing population under declining resources. The present policies like PMKSY (*Pradhan Mantri Krishi Sinchayee Yojana*) at national and state level water conservation policy initiatives such as “Telangana State Micro Irrigation Project”, “Andhra Pradesh Microirrigation Project” and “Gujarat Green Revolution Company” are aimed to address higher water productivity in agriculture in water-scarce situations. Major challenges to the large-scale adoption of water-saving technologies include farmers’ lack of knowledge about technical and economic feasibility of drip irrigation, traditional habits of cultivating rice and poor linkages among stakeholders. Continued support of research and extension agencies is hence imperative to ensure the effective scaling up of drip irrigation technology among rice farmers in the country.

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